Fermilab FERMILAB-Conf-03/144 June 2003

A NEW ANTIPROTON BEAM TRANSFER SCHEME WITHOUT COALESCING*

W. Chou#, J. Griffin, J. MacLachlan, S. Werkema, FNAL, Batavia, IL 60510, USA

Abstract

An effective way to increase the luminosity in the Fermilab Tevatron collider program Run2 is to improve the overall antiproton transfer efficiency. During antiproton coalescing in the Main Injector (MI), about 10-15% particles get lost. This loss could be avoided in a new antiproton transfer scheme that removes coalescing from the process. Moreover, this scheme would also eliminate emittance dilution due to coalescing. This scheme uses a 2.5 MHz RF system to transfer antiprotons from the Accumulator to the Main Injector. It is then followed by a bunch rotation in the MI to shorten the bunch length so that it can be captured by a 53 MHz RF bucket. Calculations and ESME simulations show that this scheme works. No new hardware is needed to implement this scheme.

INTRODUCTION

To increase the luminosity in the Fermilab Tevatron collider program Run2, one must increase the number of antiprotons (pbars) during collision. Currently the overall pbar transfer efficiency stays around 65%. Where do we lose them? From the pbar intensity plot (Fig. 1), there are two obvious places. One is in the Tevatron, about 20% loss from injection to collision. Another is in the Main Injector, about 10-15% loss during pbar coalescing. It is the latter that we want to get rid of so that the efficiency could be improved. Moreover, the new method would eliminate emittance dilution during coalescing, which also helps increase the luminosity.

The present pbar transfer scheme is as follows. In the Antiproton Accumulator, the pbars are first captured by the 2.5 MHz RF buckets. Then they split to small pieces and re-captured by the 53 MHz buckets. These small pieces are transferred to the MI 53 MHz buckets and accelerated to 150 GeV. Then a reverse process, called the coalescing, occurs. Namely, these small pieces are recombined in the 2.5 MHz buckets to form big bunches and rotated. These rotated bunches are once again captured by the 53 MHz buckets and ejected from the MI to the Tevatron. This complicated beam gymnastics works. However, beam loss and emittance dilution during coalescing have always been a concern. In the following sections, we propose a new scheme that will eliminate coalescing in the process.

NEW SCHEME

We give a step-by-step description of how this new scheme works:

1. The required longitudinal phase space density in the Accumulator is 6-8e10 pbars per eV-s, with the 1st transfer having higher density and the 9th transfer lower density. While this is a modest number compared with what was achieved in Run1b (Fig. 2) [1], we need about 50% increases from where we are now in Run2a (Fig. 3).

Figure 1: Pbar intensity plot of the 8 most recent shots as of May 9, 2003. The first big drop is the loss during coalescing. The remaining losses are in the Tevatron.

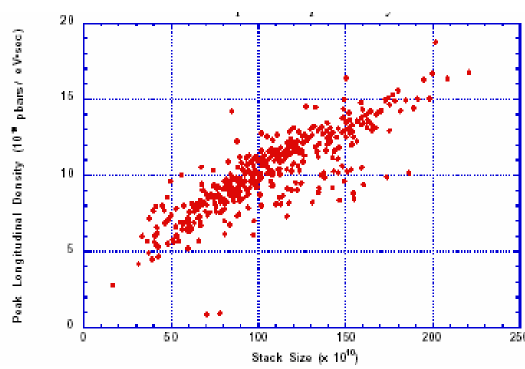

Figure 2: Run 1b longitudinal phase space density at the peak of the antiproton momentum distribution just prior to unstacking as a function of stack size, Ref. [1].

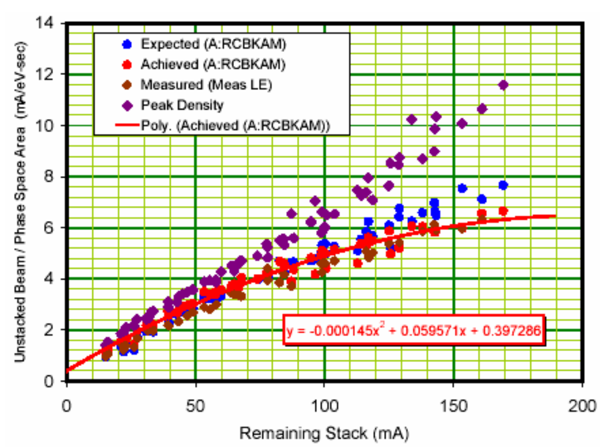

Figure 3: Run2a longitudinal phase space density as a function of stack size.

2. Use ARF4 (h = 4, 2.5 MHz, 9.5 V) to capture 4 bunches from the cooled core. The bucket size is 0.37 eV-s. Each bucket contains 3e10 pbars (Run2a goal). The bucket size will be gradually increased to 0.47 eV-s from the 1st to the 9th transfer while keeping the number of pbars per bucket constant. The corresponding voltage increase is from 9.5 to 15.3 V.
3. Move these bunches to the extraction orbit and increase the RF voltage adiabatically to 100 V for narrowing the bunches.
4. Extract the 4 bunches and inject them into the carefully phase-matched 2.5 MHz RF bucket (h = 28) in the Main Injector.
5. The MI 2.5 MHz RF is set at its maximum voltage (60 kV). A bunch rotation will occur immediately after the injection. The bunch length will be compressed to about ±6 ns. (An alternative approach is to set the MI 2.5 MHz RF at the matched voltage 0.25 kV to receive the bunches prior to bunch rotation.)
6. Capture these bunches by the h = 588 RF in the MI (52.81 MHz, 693 kV). The bunch spacing will be 396 ns.
7. Adiabatically increase the h = 588 RF voltage to 1.8 MV to increase the bucket size and narrow the bunches. Accelerate the 4 bunches to 150 GeV and inject them into the Tevatron.
8. Repeat this process 9 times.

The results obtained from analytic calculations and numerical simulations using ESME are in general agreement. Both show that this scheme works. Fig. 4 are the plots from ESME.

BEAM PHYSICS ISSUES

Longitudinal Density Dilution

The longitudinal density of the antiproton beam will decrease during the 9 transfers. In order to have 3e10 pbars per bunch, we use a bunch area of 0.37 eV-s for the 1st transfer and 0.47 eV-s for the 9th transfer. This implies a 50% increase in longitudinal density from the present operation and requires beam study in the Accumulator.

Momentum Acceptance of the MI

The measured aperture acceptance was $\Delta p/p = \pm 0.7\%$ (i.e., ± 63 MeV) [2]. The bucket height of the 53 MHz RF at 1.8 MV is ± 44 MeV. It can accommodate a 0.75 eV-s bunch. There should not be any problem at the injection.

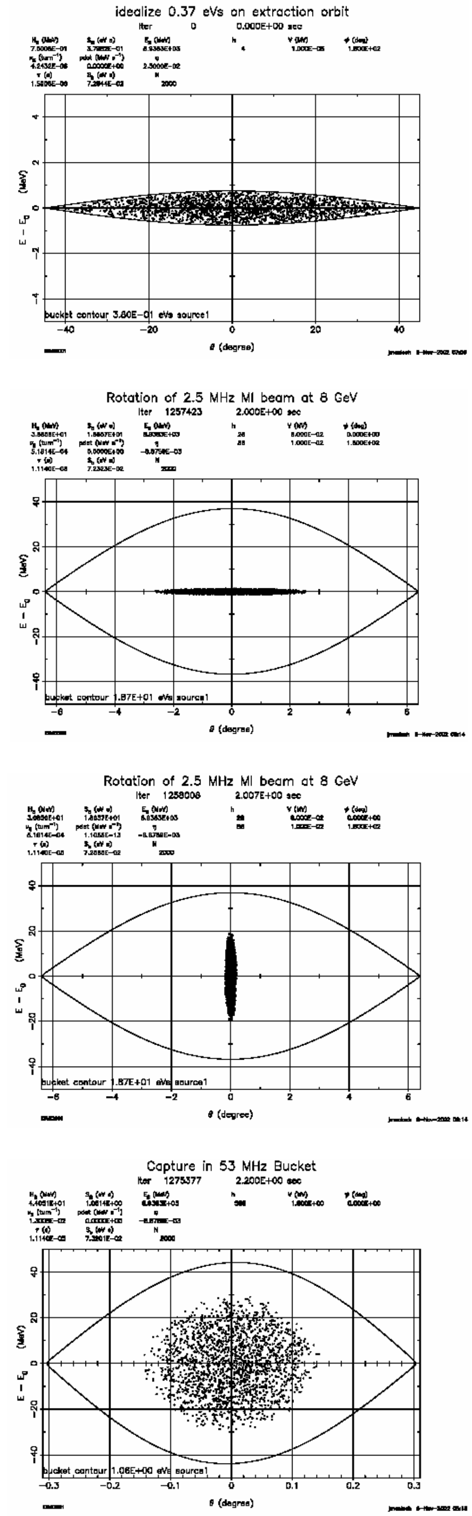

Figure 4: ESME simulation. From top down: (1) h=4 (2.5 MHz) RF capture of 0.37 eV-s pbar bunches in the Accumulator; (2) h = 28 (2.5 MHz) RF capture of pbars in the Main Injector at V_{rf} = 60 kV before the rotation; (3) after the rotation; (4) h = 588 (53 MHz) RF capture of pbars in the Main Injector and V_{rf} adiabatically increased to 1.8 MV.

*Work supported by the Universities Research Association, Inc. under contract No. DE-AC02-76CH03000 with the U.S. Dept. of Energy.
#chou@fnal.gov

Transition Crossing in the MI

The pbar bunches will be 4 times more intense than they are now when crossing the transition. But compared with the proton bunch intensity in $29 cycle (6e10), pbar bunch intensity (3e10) is only half that value. Furthermore, the longitudinal phase space density of the pbar bunches is much lower than that of the protons.

However, the large pbar bunch emittance (0.37-0.47 eV-s) is a concern. An analysis was done for the transition crossing and found that both the emittance dilution and maximum energy spread were tolerable. They are, respectively, 20% and $\pm$ 0.6% for 0.37 eV-s bunches, and 25% and $\pm$ 0.7% for 0.47 eV-s bunches.

As a fallback plan, a gamma-t jump system can be readily implemented to improve transition crossing [3].

Another option is to use a third harmonic RF system during transition crossing. The experiment was done on the Main Ring at Fermilab. The hardware exists and can be installed in the Main Injector.

Beam Loading during Bunch Rotation

During bunch rotation using the 2.5 MHz RF in the MI, the beam loading of the 53 MHz RF needs to be compensated. There are two possible solutions: (i) to install a feedback and a feedforward system (which is an on-going activity); (ii) to lower the effective cavity impedance by a factor of 3-4 by lowering the screen voltage from 2 kV to -100 V (a proposal by J. Griffin, which needs to be tested).

HARDWARE AND SOFEWARE ISSUES

An important advantage of this new method is that no new hardware is needed for its implementation. Several issues regarding hardware and software are addressed below:

- Although the maximum voltage of the ARF4 can reach 900 V, we found that the 2.5 MHz bunch rotation and 53 MHz RF capture work better if we use 100 V instead of 900 V.
- A technical challenge is the regulation requirement of the ARF4 to the level of several volts in order to create a 0.37 eV-s bucket. But this is possible. [4]
- There is a slight frequency mismatch between the Accumulator 2.5 MHz RF and the MI 2.5 MHz RF (< 3 kHz). But this can be taken care of. [5]
- The MI 2.5 MHz RF voltage can be jumped quickly from 0.25 kV to 60 kV for bunch rotation [5]. This system has a nominal Q = 100, which gives a field decay time constant τ = 12.7 μs. Measurement shows the actual decay time is shorter. Therefore, it is possible to use the matched RF buckets to receive bunches from the Accumulator prior to the rotation (an option).
- Presently the MI 53 MHz RF cannot operate at its full voltage (4 MV) at injection due to tuner sparking. This will limit the achievable bucket size and need to be discussed with the RF group. We assumed 1.8 MV in this study.

BEAM STUDY PLAN

A two-phase beam study plan is under consideration for testing this new method.

Phase I

2.5 MHz pbar beam transfer, capture and bunch rotation:

- Develop MIRF procedures:
  1) RFI assistance to build and adjust I6 files for the required 2.5 MHz and 53 MHz RF sequence
  2) Use of a 2.5 MHz bunch length monitor
- Develop ARF procedures:
  To build and adjust ARF3 and ARF4 sequence for 2.5 MHz beam transfer to the Main Injector

Phase II

Develop procedures to maximize the pbar longitudinal density extracted from the Accumulator and determine what pbar longitudinal density is achievable:

- New version of VSA software that determines frequency and bucket area for extraction
- Test software on proton beam
- Test software on pbars left over after a shot (abort transfers in MI)
- Verify that the required 50% increase in core longitudinal density can be achieved by doing a shot to the Tevatron with a pbar stack of at least 120 mA.

ACKNOWLEDGEMENT

There have been helpful discussions with K. Koba, B. Chase and D. Perterson on this new method.

REFERENCES

[1] V. Bharadwaj et al., “Fermilab Collider Run 1b Accelerator Performance,” FERMILAB-TM-1970 (April 1996).
[2] K. Koba, private communication.
[3] W. Chou et al., “Design of a Gamma-t Jump System for Fermilab Main Injector,” Proc. PAC 1997 (Vancouver, Canada), pp. 994-996.
[4] D. Peterson, private communication.
[5] B. Chase, private communication.